# STUDY OF THE DEPENDENCE OF THE WIRE TENSION AS A FUNCTION OF TEMPERATURE FOR A DRIFT TUBE OF THE ATLAS MUON SPECTROMETER

**Activity report**

*Student: Nicolò Spagnolo, Liceo Scientifico Farnesina, Roma*
*Tutors: Saverio Braccini and Vincenzo Russo, INFN, Laboratori Nazionali di Frascati*

## General introduction

ATLAS (A Toroidal LHC ApparatuS) is a complex system for particle detection at the Large Hadron Collider (LHC), the biggest particle accelerator that will be built at the European Laboratory for Particle Physics (CERN) in Geneva. ATLAS is an international collaboration between 153 institutes from 35 nations. It is composed by many sub-detectors, as shown in Fig.1. The muon spectrometer is composed of about 1100 Monitored Drift Tube (MDT) chambers. The scheme of a MDT chamber is shown in Fig.2. The Laboratori Nazionali di Frascati is in charge of the construction of 94 of them. The MDT chambers are the main part of the muon detector, as they have the important goal of tracking the path of these particles with very high accuracy. Each chamber is made of two multilayers of drift tubes connected by an aluminium structure called spacer. The spacer and the tubes are made of the same material in order to reduce deformation effects due to thermal expansion.

The drift tubes are the basic detection element of the MDT chambers. They are a very light structure, only 400 μm thick, with a W (97%)-Re (3%) 50 μm central wire. The wire has a mechanical tension between 343 and 357 g. Each tube is filled with a mixture of gases ($Ar/CO_2$).

In the accelerator two beams of protons are made colliding. As a consequence of these collisions many particles are created. Most of them are stopped and detected in the inner part of the detector. Muons, instead, have the property of passing very easily through matter and are able to reach the muon detector. Muons are charged particles, very similar to electrons but about 200 times heavier. To measure their momentum, the magnet system deviates their path and the MDT chambers detect them. When a muon passes through a drift tube, it ionises the gas mixture. As the wire is given an electrical high voltage, the electrons produced by the ionisation are attracted to the centre of the tube, in correspondence of the wire. The time that passes between the ionisation and the collection of the electrons by the wire is measured. As the speed of the electrons is known, the point in which the muon track has passed is calculated. The muon track is reconstructed by using the signals of several tubes. In order to make these measurements with the required high accuracy, it is fundamental to know the position of the wires in space and in particular inside the tubes.

## Description of the experiment

### *Theoretical view of the problem*

The experiment I have performed has the goal of establishing which kind of mathematical law controls the mechanical tension of the wire of the ATLAS drift tubes as a function of temperature. The sagitta of the wire, and so its position in space, is determined by the tension. This is very important because, as explained in the previous paragraph, it influences the accuracy of the ATLAS muon spectrometer.

Before starting the measurements, I have studied the problem theoretically. The two following physical laws are necessary to study the problem:

(a) $\tau = S \cdot E \cdot \frac{\Delta l}{l} + \tau_0$ where τ is the tension, S is the section of the wire, E is a constant proper of the material, called Young's module, l is the length of the wire, Δl is due an external force and $\tau_0$ is the original tension

(b) $\Delta l = K \cdot l_0 \cdot \Delta T$ where K is the constant of thermal expansion, proper of the material, and ΔT is the change in temperature.

The expansion of the wire depends also on the expansion of the tube, as the wire is crimped to the tube at the two ends. As $K_{Al}$ (the constant of the thermal expansion of aluminium) is larger than $K_W$ (the constant of the material of the wire), the tube has a bigger expansion (Table 1). This is shown in Fig. 3. Therefore:

(c) $\Delta l_{real} = \Delta l_{Al} - \Delta l_W = (K_{Al} - K_W) \cdot l_0 \cdot \Delta T$

This is the law for the real expansion of the wire. We can now insert it in the expression (a):

(d) $\tau = S \cdot E \cdot (K_{Al} - K_W) \cdot \Delta T \cdot \frac{l_0}{l_0}$

Since $\Delta T = T - T_0$, it follows that:

(e) $\tau = \frac{\pi}{4} \cdot d^2 \cdot E \cdot (K_{Al} - K_W) \cdot T - \frac{\pi}{4} \cdot d^2 \cdot E \cdot (K_{Al} - K_W) \cdot T_0 + \tau_0$

As the only parameters in this expression are the tension and the temperature, this leads to:

$\tau = A \cdot T + B$

which is the law of a linear dependence. After having deduced which is the kind of mathematical law, the values of the parameter A and B can be calculated using the values reported in Table 1. The values A = 1.62 g/ºC and B = 317.48 g are found, considering $T_0$ = 20°C and $\tau_0$ = 350g.

## *Description of the instrumentation*

Two different methods have been used to determine the tension of the wire of ATLAS drift tubes.

1) WIRE TENSION METER (WTM) - Fig.4

To measure its mechanical tension, the wire is excited at its resonance frequency. To make it oscillate, the sag of the tube is increased. The computer excites the wire with a frequency scanning using a high voltage square wave. When the resonance frequency is reached, the wire starts to oscillate under the effect of the electric field. The nearer is the frequency of oscillation to the resonance one, the bigger is the oscillation amplitude. The resonance frequency is detected by measuring the change in the capacitance of the wire-tube system. The computer draws a chart with the amplitude as a function of the frequency. The tension of the wire is calculated using the following formula:

(f) $\tau = \frac{L^2 \cdot d^2 \cdot \rho \cdot \pi \cdot \nu^2}{g}$

where ν is the oscillating resonance frequency, L the length, d the diameter, ρ the density of the wire and g the acceleration of gravity. This system has the advantage of a high accuracy and a fast measuring time. The computer measures also the temperature of the tube.

2) WIRE STRETCH METER CAEN MODEL SY502 – Fig.5

This system is based on the interaction between a magnetic field and the electrically excited wire. The stretch meter is connected to the two ends of the wire and a magnet is positioned in the middle of the tube, in order to create a magnetic field in that point. The wire is made oscillating at his fundamental frequency, using periodic electrical signals. The module's processor calculates the wire tension using the formula (f), after having measured the oscillating frequency ν. To measure the temperature a thermometer with two sensors is used. The sensors are connected with the two ends of the tube. As sometimes there is a sensible difference between the two measured temperatures, the average is calculated.

### *Description of the procedure of measurement*

The first part of the work consists on measuring with the CAEN system the change in the tension of the drift tubes caused by the variation of temperature. The sensors of the thermometer are connected to the two ends of the tube, the magnet is positioned by the centre of the tube and the stretch meter is connected to the wire-tube system. Several measurements are then taken for each tube when there is a sensible change in the temperature. The change in temperature is caused by thermal excursion during the day. Four tubes have been measured in a range of temperature of about four or five degrees for each tube. For the tube n°187928 the measurements have been repeated in two different days in order to verify if they can be reproduced. A good reproducibility of the measurements has been observed.

With the same tubes, the measurements are repeated with the WTM system. As this module is inside a “clean room”, where the temperature is controlled, it is possible to have a little change in temperature with respect to the other method. Few data have been collected for this reason. All the data collected are reported in Table 2.

## Analysis of the data and final conclusions

With the CAEN system it has been possible to take enough measurements to draw a good chart in order to verify the linear dependence of the tension of the wire as a function of the temperature. Data from four different tubes have been collected and Charts 1-4 have been drawn with the Microsoft Excel software. The charts put in clear evidence a good linear dependence.

The uncertainties in the temperature are determined by the accuracy of the thermometer (0.1 °C) and also by the difference that sometimes there has been between the temperatures measured by the two sensors. The uncertainties in the tension are evaluated from the instability of $\pm$ 0.05 g that the CAEN system has when taking repeated measurements.

The parameter A is evaluated in two different ways. First the Excel software program has been used. Since Excel does not calculate the uncertainties, a graphical method has also been used. This method consists on drawing the lines with the maximum and minimum angular coefficient and in making the average. The difference gives us the uncertainty. The maximum and minimum angular coefficients are calculated by knowing two points for which the corresponding line passes. The following formula is used: $m = \frac{y_2 - y_1}{x_2 - x_1}$, where y and x are the coordinates of the points. Good agreement is found between Excel and the graphical method (Table 3).

Only two measurements of the tension have been taken for each tube with the WTM system for the reasons explained in the previous paragraph. As for two points passes only one line its equation can be easily calculated. In this case only the Excel software is used.

Table 3 shows all the results for the parameter A. The difference between the WTM results and the CAEN ones is also reported. Despite of the good linear dependence, there is not a good agreement between the theoretically calculated values and the experimental measurements for three of the four tubes. Significant discrepancies are found between the two methods (CAEN and WTM) and between different tubes when measured with the same method. The reasons for this behaviour are unknown up to now and more investigations are necessary to understand the problem.

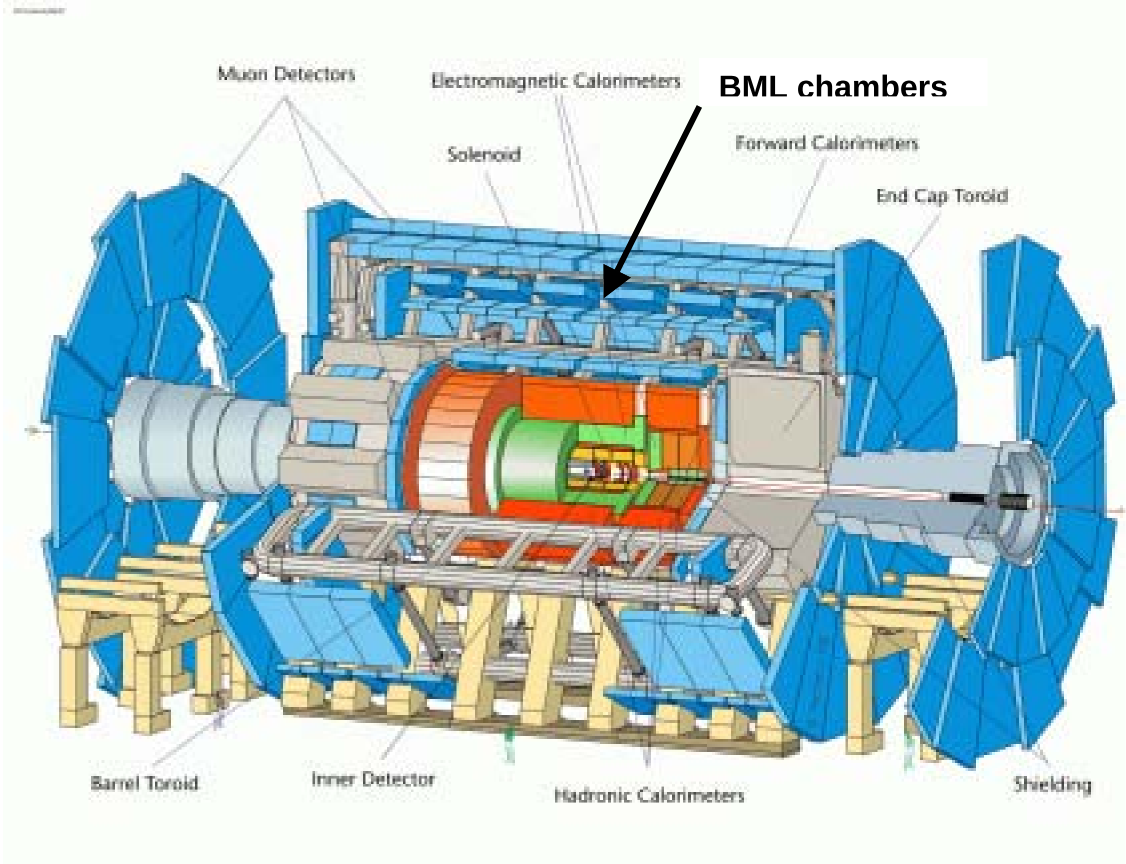


Fig.1 – Picture describing the ATLAS detector. The arrow indicates where the BML chambers built at Laboratori Nazionali di Frascati are positioned.

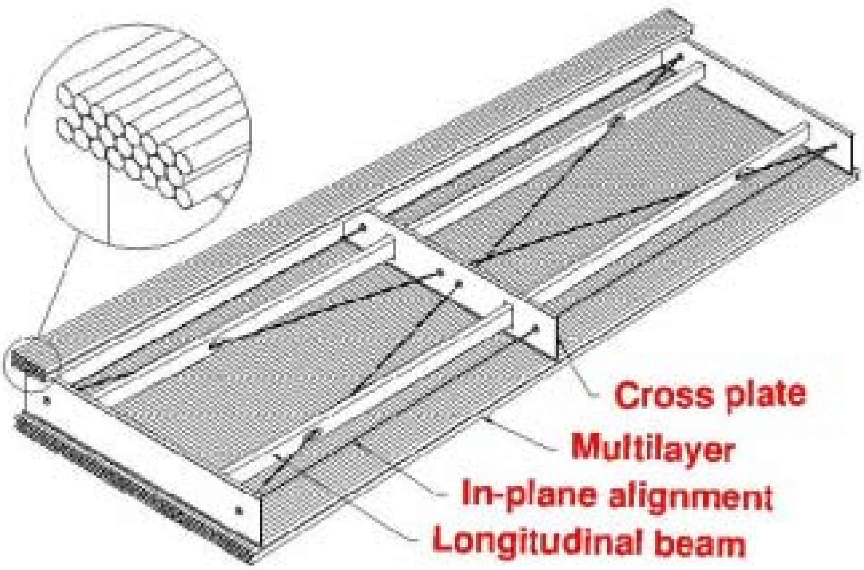


Fig.2 – Scheme of an ATLAS MDT chamber.

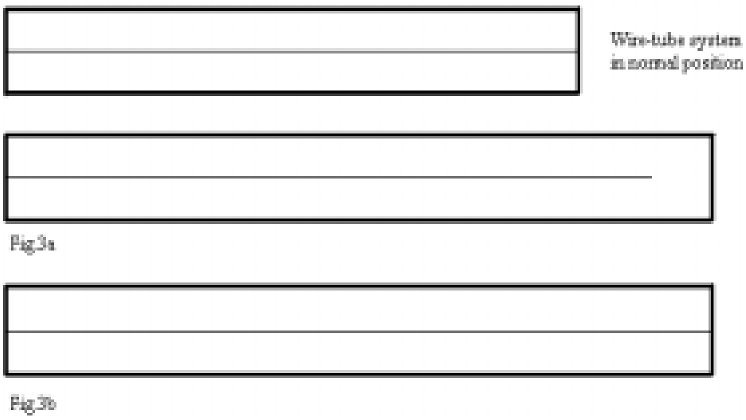


Fig.3 – Schematic view of the thermal expansion of an ATLAS drift tube. In Fig. 3a it is represented the expansion of the wire-tube system if the wire was crimped only at one of the ends. Fig 3b represents the real expansion of the wire-tube system.

| **DRIFT TUBE** | |
|---|---|
| Density | 2.73 $g/cm^3$ |
| Thermal expansion ($K_W$) | $24 \cdot 10^{-6}$ 1/°C |
| Young's modulus | 70000 $N/mm^2$ |
| Wall Thickness | 400±20 μm |

| **WIRE** | |
|---|---|
| Density | 19.3 $g/cm^3$ |
| Thermal expansion ($K_{Al}$) | $4.2 \cdot 10^{-6}$ 1/°C |
| Young's modulus | 410000 $N/mm^2$ |
| Diameter | 50 mm |
| Weight per meter | 37.8 mg/m |
| Rupture limit | 620 g |
| Electrical resistance | 44 Ω/m |

Tab.1 Characteristics of ATLAS drift tubes.

Fig.4 – Photograph of the WTM system.

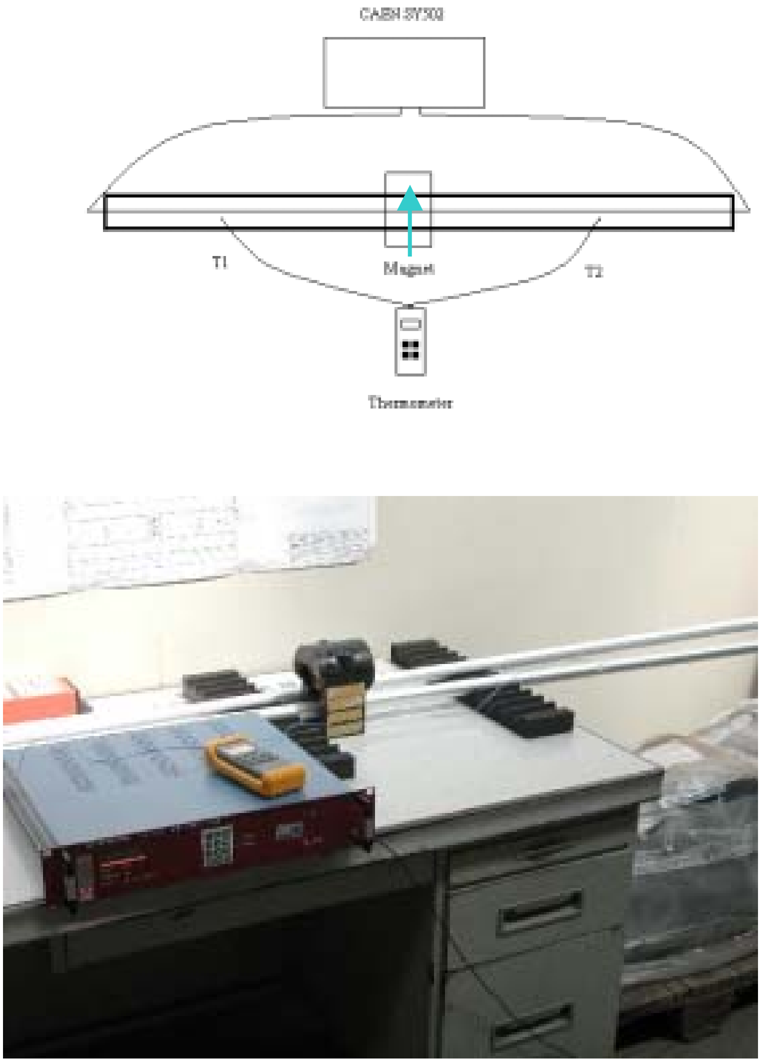


Fig.5 – Scheme and photograph of the CAEN SY502 system. The arrow in the scheme indicates the magnetic field.

| Tube n° | T1 (°C) | T2 (°C) | T aver. (°C) | Tens (gr) |
|---|---|---|---|---|
| 257349 | 24.2 | 24.2 | 24.2 | 349.25 |
| 257349 | 25.2 | 25 | 25.1 | 350.15 |
| 257349 | 26 | 25.8 | 25.9 | 351.1 |
| 257349 | 27.7 | 27.1 | 27.4 | 352.35 |
| 257349 | 28.2 | 27.8 | 28 | 353 |
| 257349 | 28.5 | 28.3 | 28.4 | 353.45 |
| | | | | |
| 187928 | 25.9 | 25.9 | 25.9 | 342.65 |
| 187928 | 26.6 | 26.7 | 26.65 | 343.25 |
| 187928 | 27.4 | 27.4 | 27.4 | 344.1 |
| 187928 | 27.9 | 27.9 | 27.9 | 344.55 |
| 187928 | 28.6 | 28.7 | 28.65 | 345.58 |
| 187928 | 29.2 | 29.2 | 29.2 | 346.1 |
| 187928 | 29.6 | 29.8 | 29.7 | 346.84 |
| | | | | |
| 42643 | 28.1 | 28.1 | 28.1 | 366.37 |
| 42643 | 28.7 | 28.7 | 28.7 | 367.23 |
| 42643 | 30.3 | 30.1 | 30.2 | 368.85 |
| 42643 | 30.7 | 30.7 | 30.7 | 369.43 |
| | | | | |
| 121028 | 27.4 | 27.4 | 27.4 | 363.45 |
| 121028 | 28 | 27.8 | 27.9 | 364.4 |
| 121028 | 29.6 | 29.4 | 29.5 | 366.75 |
| 121028 | 30.2 | 30.1 | 30.15 | 367.6 |

| Tube n° | WTM Temp (°C) | Tens (g) |
|---|---|---|
| 257349 | 22.83 | 346.5 |
| 257349 | 21 | 343.7 |
| 187928 | 22.83 | 337.5 |
| 187928 | 21 | 336 |
| 42643 | 22.83 | 360.7 |
| 42643 | 21 | 357.4 |
| 121028 | 22.83 | 359.8 |
| 121028 | 21 | 357.3 |

Tab.2 Measurements of the wire tension of ATLAS drift tubes. On the left side the measurements taken with the CAEN system are reported, on the right with the WTM.

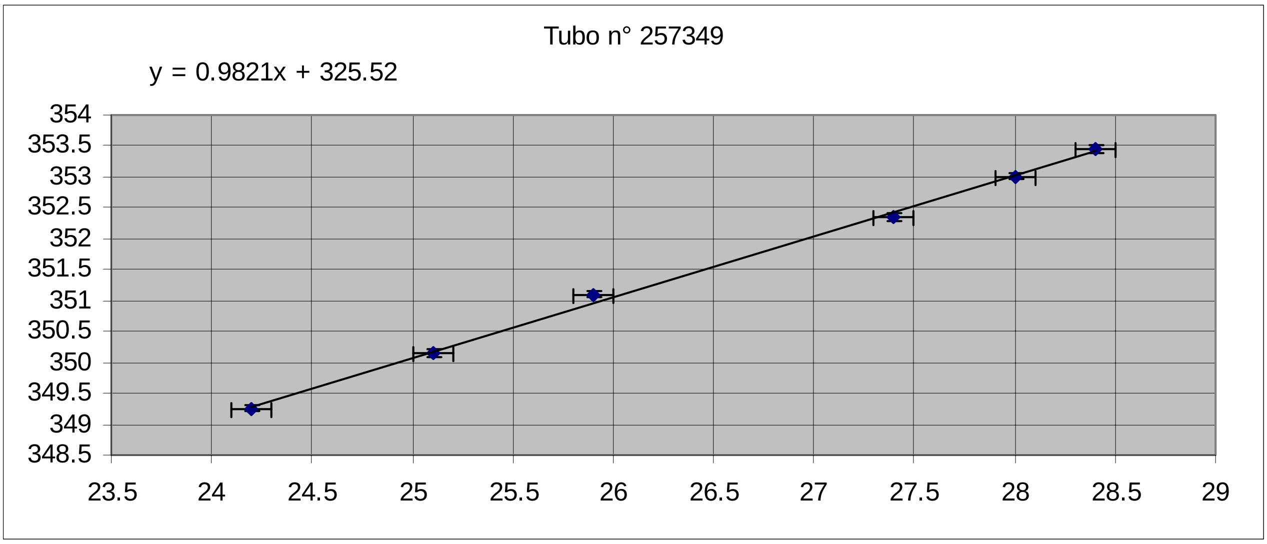


Chart 1 – Tube number 257349 measured with CAEN system.

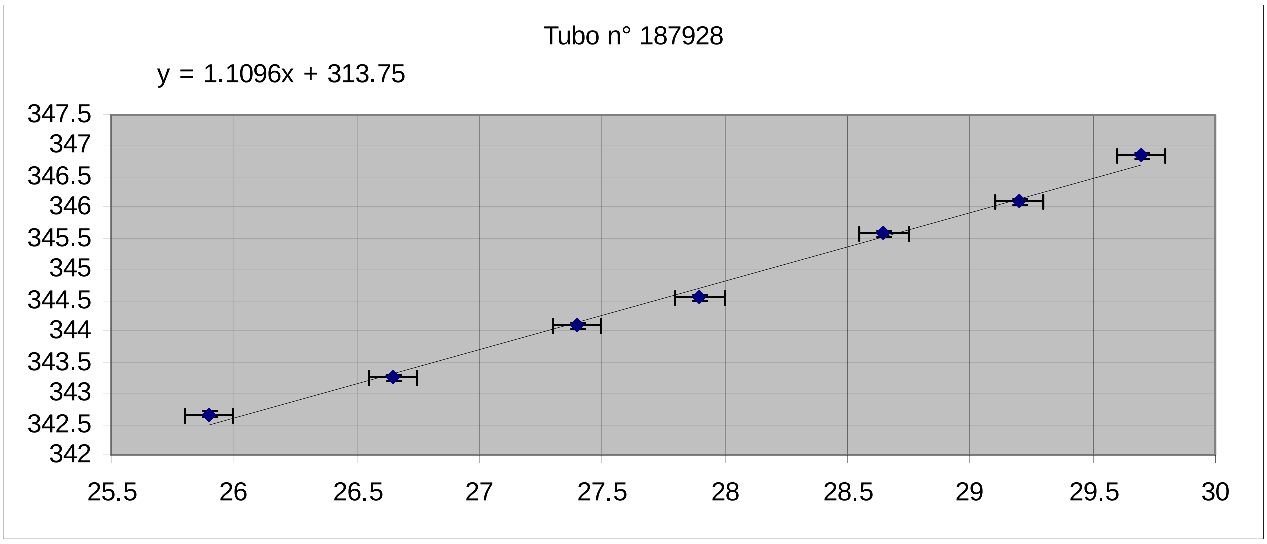


Chart 2 – Tube number 187928 measured with CAEN system.

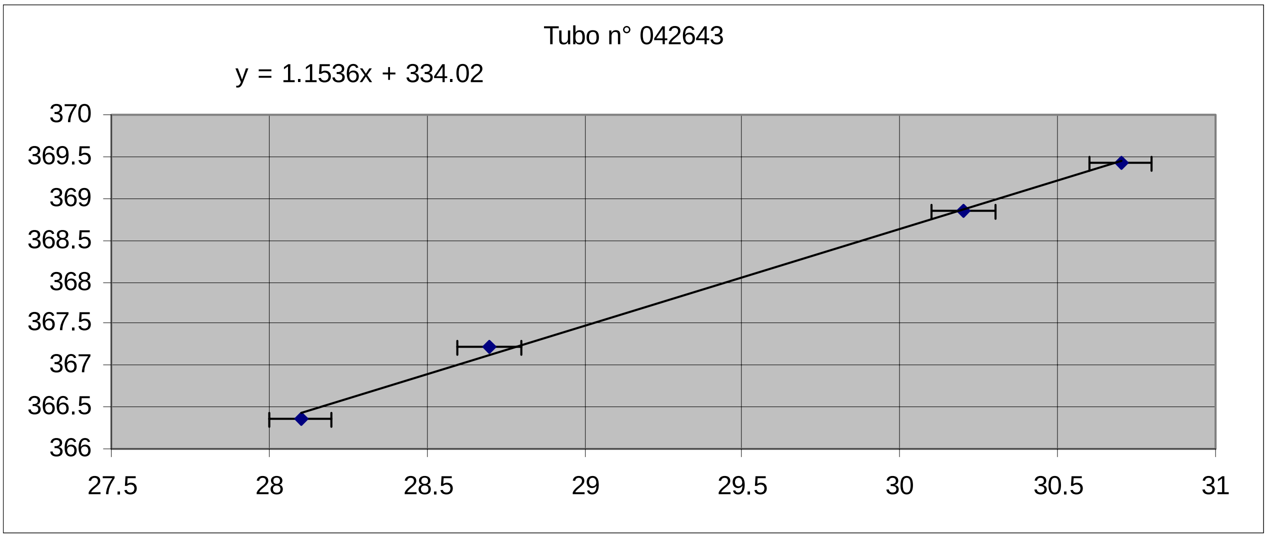


Chart 3 – Tube number 042643 measured with CAEN system.

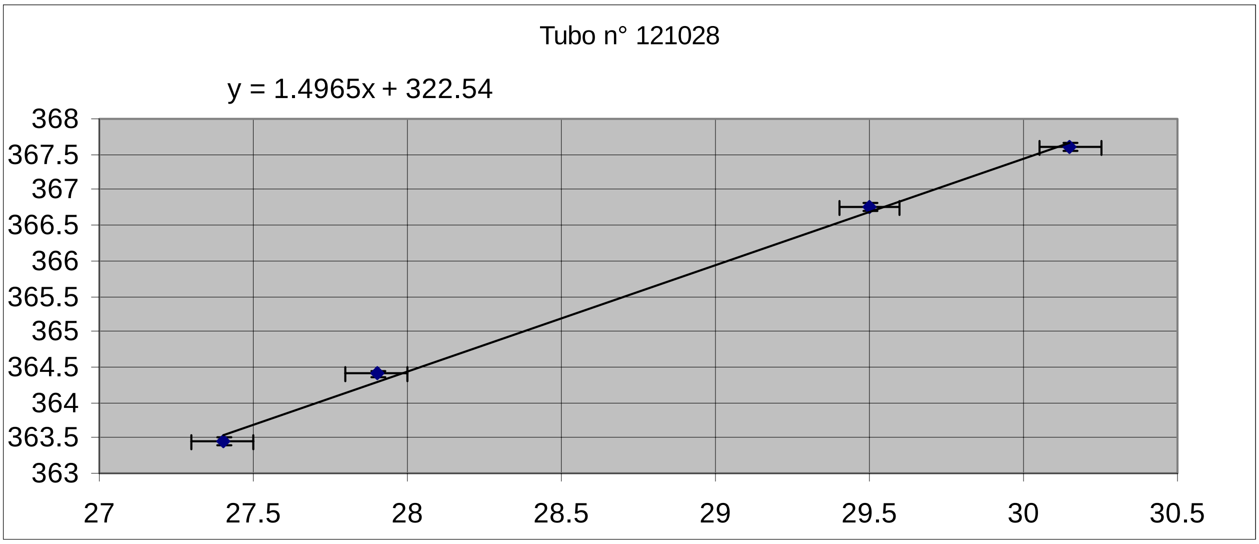


Chart 4 – Tube number 121028 measured with CAEN system.

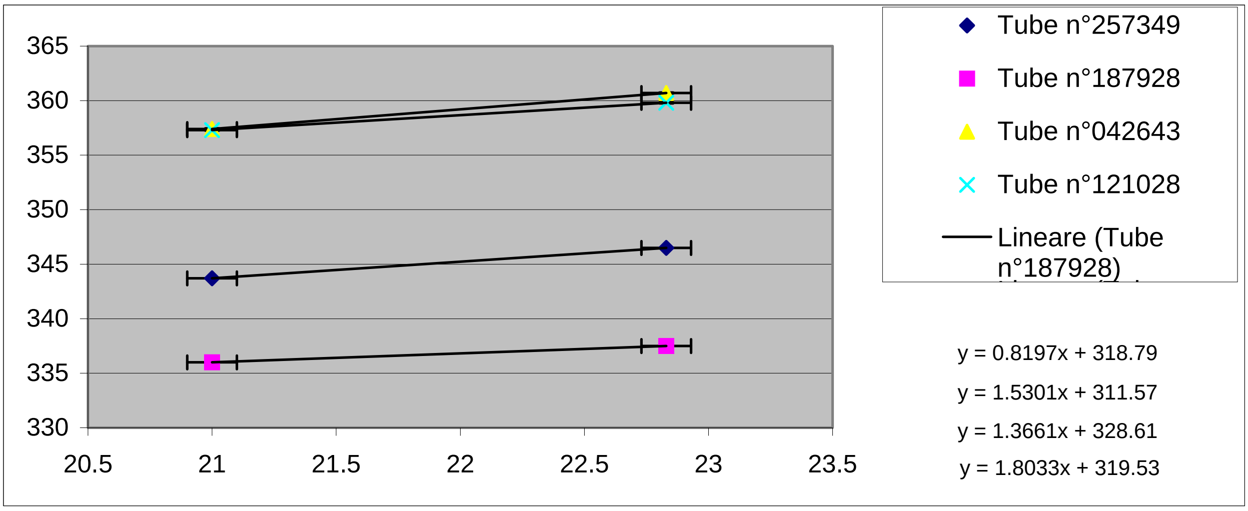


Chart 5 – Comparison of the measurements taken with the WTM system for the four tubes.

| Tube n° | A (CAEN) | A (WTM) | Δ | A (CAEN) Gr.M. |
|---|---|---|---|---|
| 257349 | 0.98 g/°C | 0.82 g/°C | 0.16 g/°C | 1.00 ± 0.10 g/°C |
| 187928 | 1.11 g/°C | 1.53 g/°C | -0.42 g/°C | 1.06 ± 0.10 g/°C |
| 042643 | 1.15 g/°C | 1.37 g/°C | -0.22 g/°C | 1.20 ± 0.15 g/°C |
| 121028 | 1.5 g/°C | 1.8 g/°C | -0.30 g/°C | 1.50 ± 0.20 g/°C |

Tab.3 – Comparison between the experimental values of the parameter A obtained with both CAEN and WTM system using the Excel software program. Column number 5 shows the values of A from CAEN data calculated with the graphical method and the respective uncertainties. The theoretically calculated value is 1.62.